Guidelines for Applying IEC Standards to Electrical Distribution Equipment

Part 5

IEC equipment standards

high-voltage switchgear & controlgear

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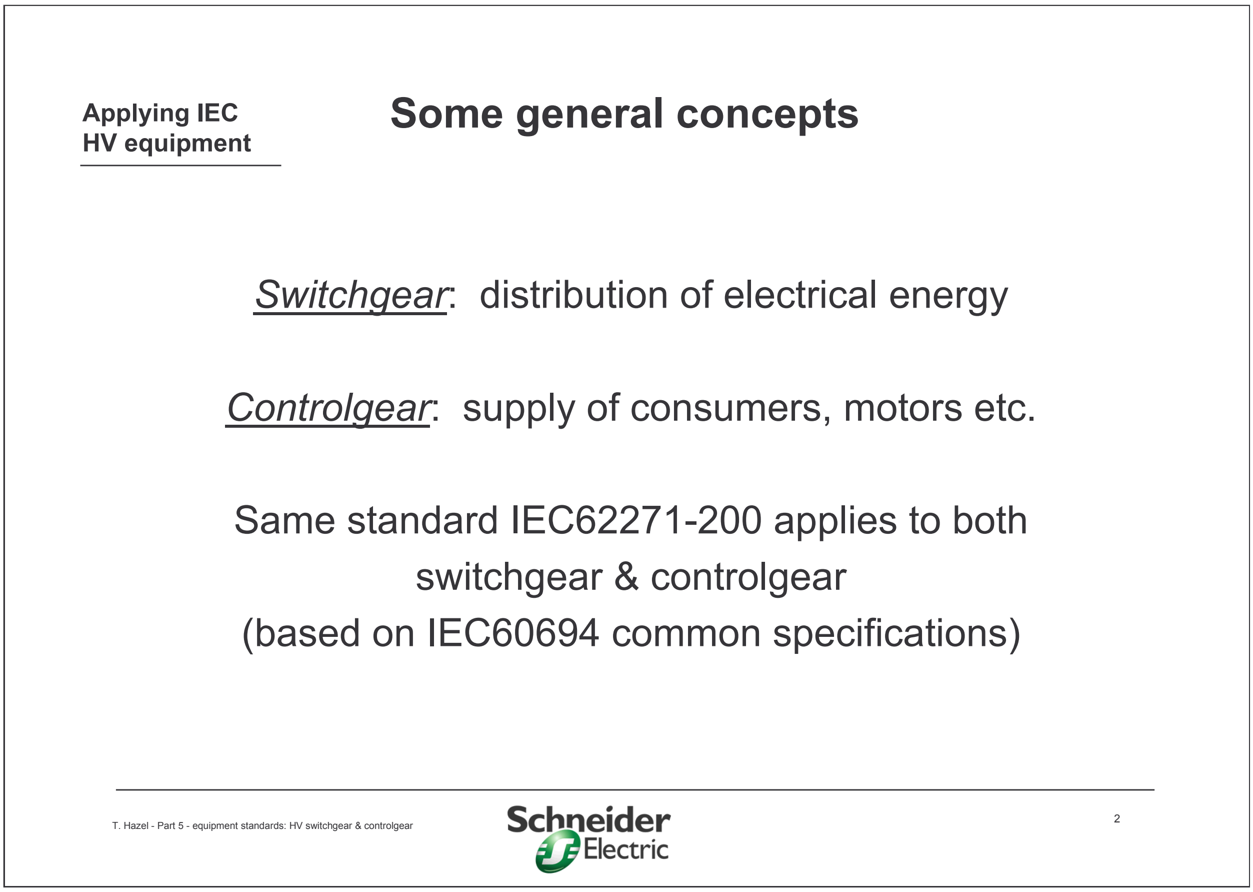
switchgear and controlgear

As mentioned in part 2 of the tutorial the IEC term *switchgear and controlgear* is used for all assemblies containing switching devices. *Switchgear* is used for distribution of electrical energy whereas *controlgear* for supply of consumers. Terms such as *motor control centers*, or *panel boards* are not used in IEC standards. The information in this part of the tutorial is applicable to all such equipment even if the terms are not used in the IEC. To facilitate reading, the term *switchgear* will often be used in this part of the tutorial to mean *switchgear and controlgear*.



Some general concepts

Switchgear: distribution of electrical energy

Controlgear: supply of consumers, motors etc.

Same standard IEC62271-200 applies to both
switchgear & controlgear
(based on IEC60694 common specifications)

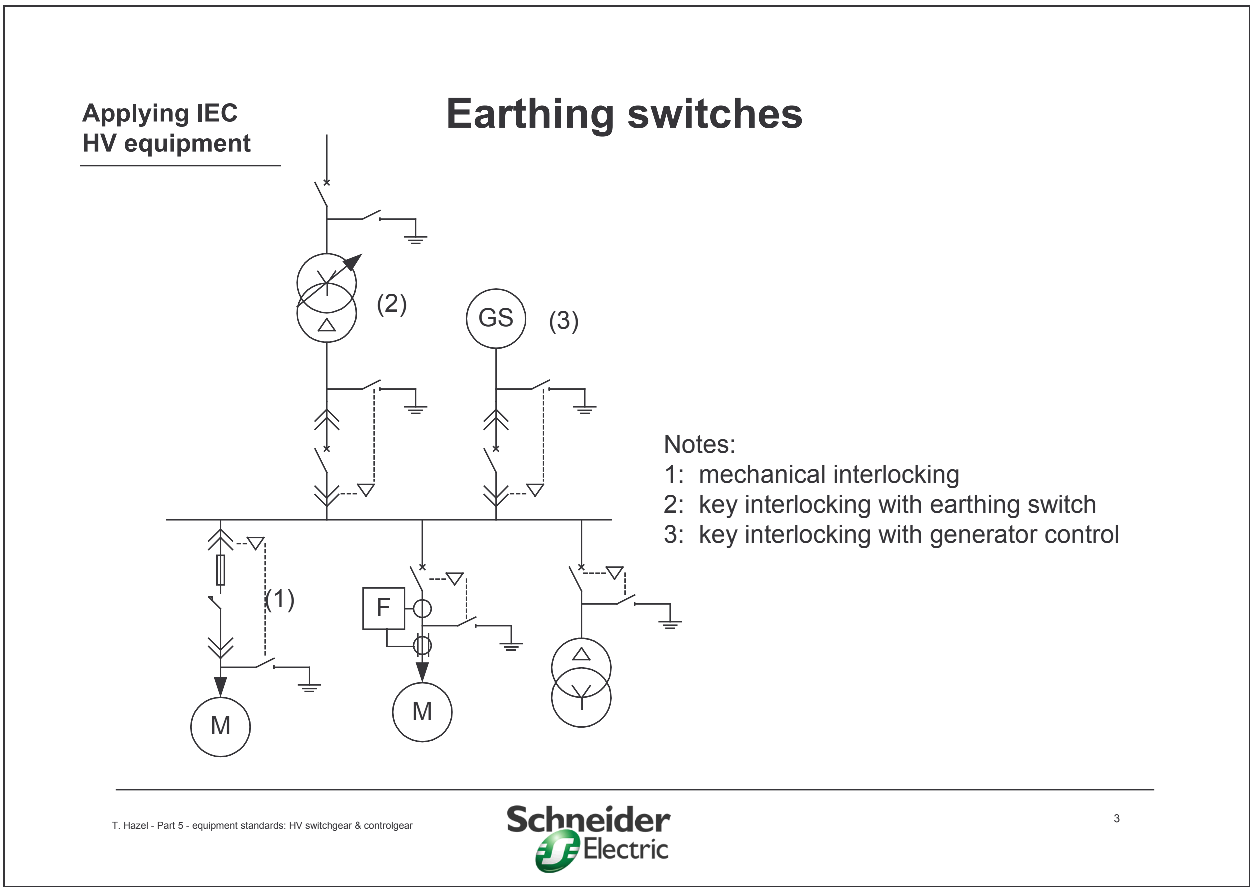
high-voltage switchgear and controlgear

IEC62271-200 a.c. metal-enclosed switchgear and controlgear for rated voltages above 1kV and up to and including 52kV (replaces IEC60298) is a very important standard since most industrial applications have switchgear in this voltage range. This standard which is applicable for 50Hz and 60Hz can also be used for air-insulated equipment at higher voltages.

Product standards are compared to Russian dolls in part 1 of the tutorial. IEC62271-200 is a particular application of the more general standard *IEC60694 common specifications for high-voltage switchgear and controlgear standards* which applies to all equipment above 1000V. IEC62271-200 often refers to sub-clauses of IEC60694 and specifies additional information applicable to medium-voltage switchgear.

new numbering

As mentioned in part 1 the high-voltage standards have been renumbered. Please refer to the table in the annex containing a list of the new numbering of these standards.



Applying IEC
HV equipment

Earthing switches

Notes:
1: mechanical interlocking
2: key interlocking with earthing switch
3: key interlocking with generator control

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earthing switches

Earthing switches are not a requirement of IEC standards but are commonly used by European manufacturers. They allow safe maintenance without the use of temporary earthing connections.

interlocking

Interlocking must prevent closing of earthing switches when the main switch is not in the open position or withdrawn (§5.11 IEC62271-200).

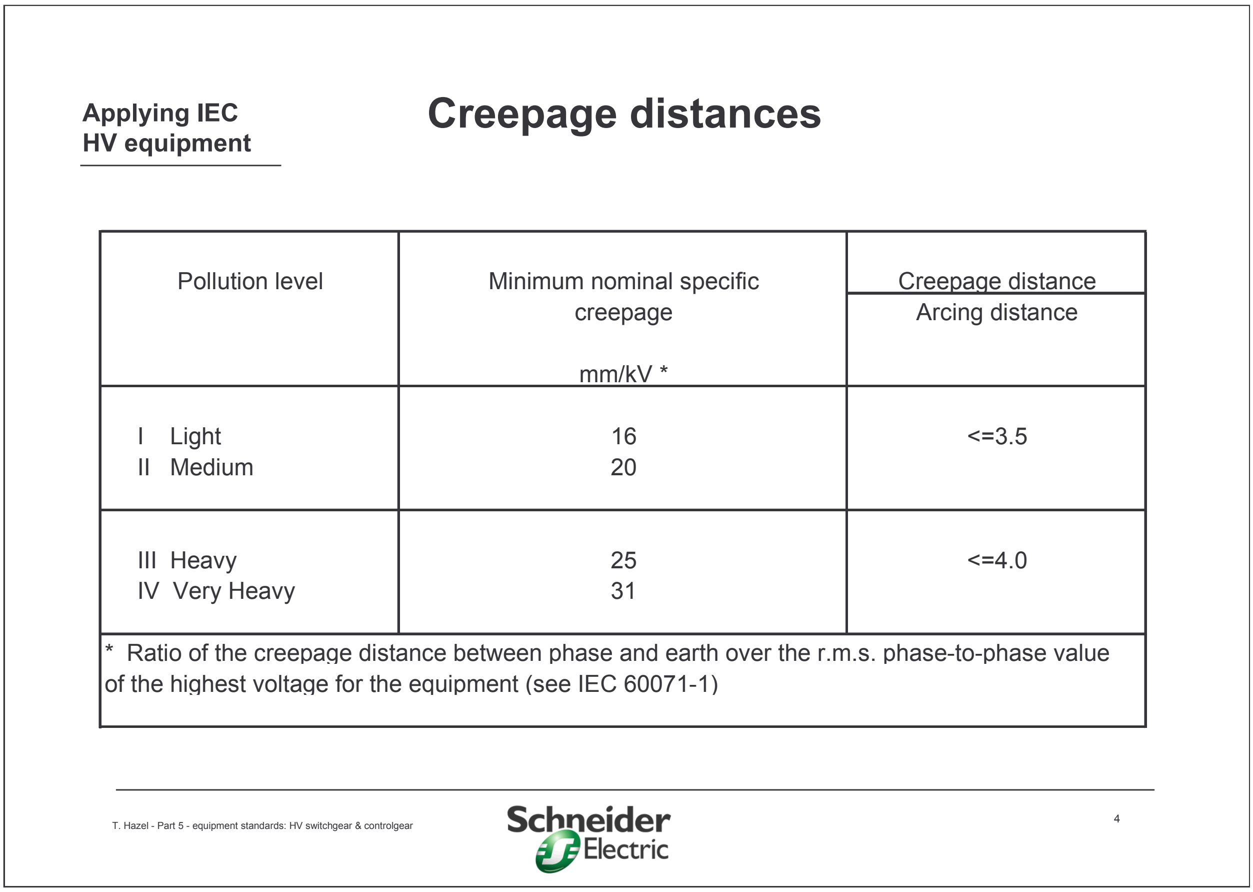
With transformer incomers key interlocking with the upstream earthing switch is recommended (downstream earthing switch can be closed only if upstream earthing switch is closed).

For generators key interlocking is also recommended (earthing switch can be closed only if generator selector is in the “off” position).

Key interlocking between different manufacturers can most easily be done by linking each manufacturer’s key on a commom welded key ring (not necessary to use the same key).

making capacity

Earthing switches normally don’t require a making capacity if correct interlocking is provided. Making capacity should be specified only if there are doubts that interlocking can be achieved.



Creepage distances

Pollution level	Minimum nominal specific creepage mm/kV *	Creepage distance Arcing distance
I Light	16	<=3.5
II Medium	20	
III Heavy	25	<=4.0
IV Very Heavy	31	

* Ratio of the creepage distance between phase and earth over the r.m.s. phase-to-phase value of the highest voltage for the equipment (see IEC 60071-1)

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creepage distance specification

The creepage distance is defined by a multiplying factor based on the level of pollution at the site. There is often confusion in determining the total creepage distance based on the mm/kV value. This is due to the fact that insulators are installed between phase and neutral, not phase-to-phase but the phase-to-phase voltage is to be used. Sometimes the phase-to-neutral voltage is used rather than the phase-to-phase voltage. Sometimes the rated system voltage rather than the highest voltage for equipment Um is used.

Example: 5.5kV system in Algeria, heavy pollution.

Creepage distance = (7.2kV)(25mm/kV) = 180mm for insulators connected between phase and earth.

Applying IEC
HV equipment

Internal arc resistance of high-voltage assemblies

General ideas

- For protection of personnel
- Not a requirement of IEC. Definitions & testing specified in annex A IEC62271-200.
- Short-circuit current should be same as short time withstand. Protection setting should be based on test duration.

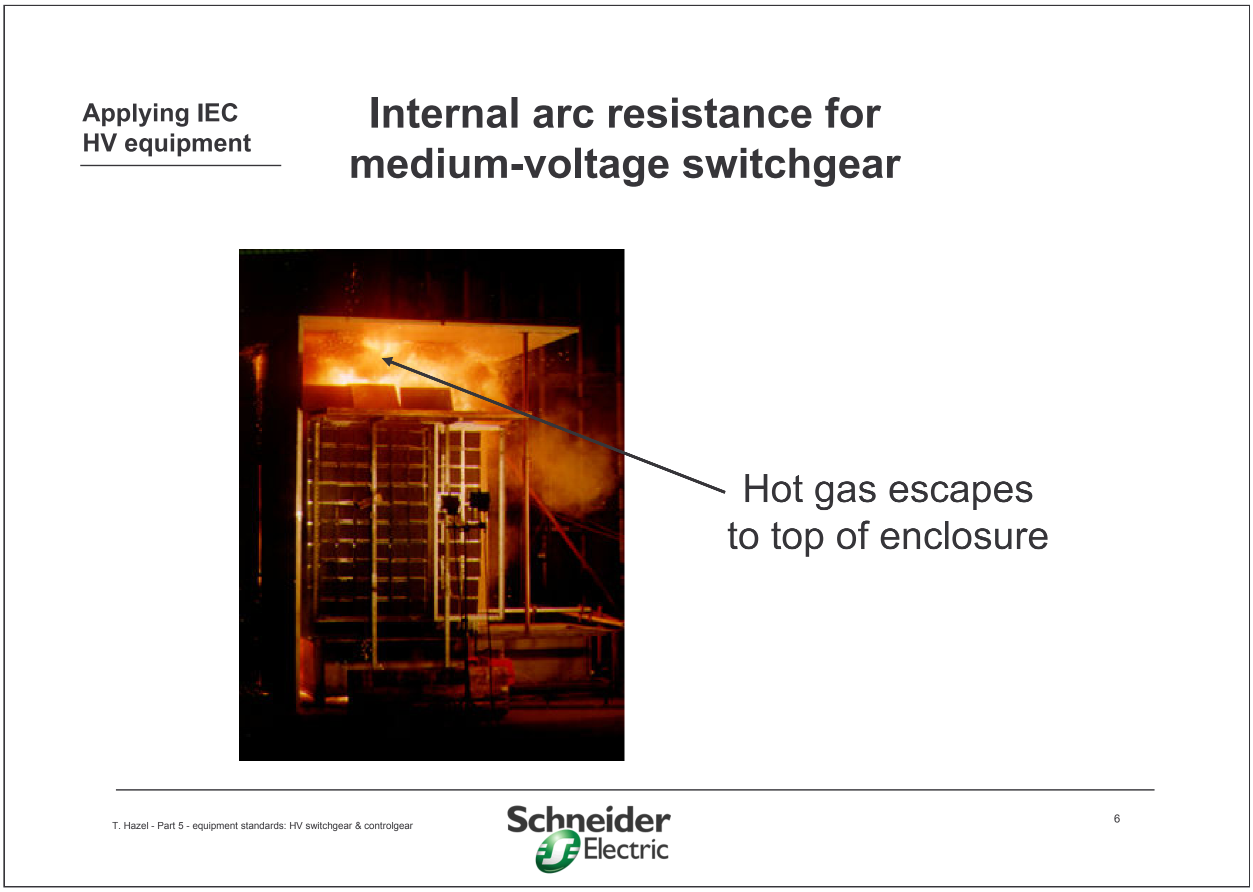
5 criteria

- doors etc. do not open
- flaps etc. do not fly off
- no holes appear in envelope
- no ignition of indicators
- earthing connections remain effective

internal faults

It is becoming common in industrial plants to require medium-voltage switchgear to be *arc resistant*. This concept and the relevant testing is described in Annex A of IEC62271-200. It is important to know that IEC62271-200 does not require that switchgear be arc resistant, but just describes the 5 criteria which are to be met and how compliance can be demonstrated. There is often confusion in the correct application of the concept of arc-resistance to the switchgear purchased for a particular project, either by overspecifying requirements or by incorrectly specifying accessory equipment such a protection gear.

Sub-clause A.4.1 recommends that the magnitude of the test current should correspond to the rated short-time withstand current. Annex A does not however, recommend that the duration of the test current be the same as the rated duration of the short-time withstand current since protection gear will eliminate the faults quickly. Sub-clause A.4.5 gives recommended values of 0.1s, 0.5s and 1s. 0.1s is adequate to test the equipment for the pressure increase due to the internal arc.



Applying IEC
HV equipment

Internal arc resistance for medium-voltage switchgear

Hot gas escapes
to top of enclosure

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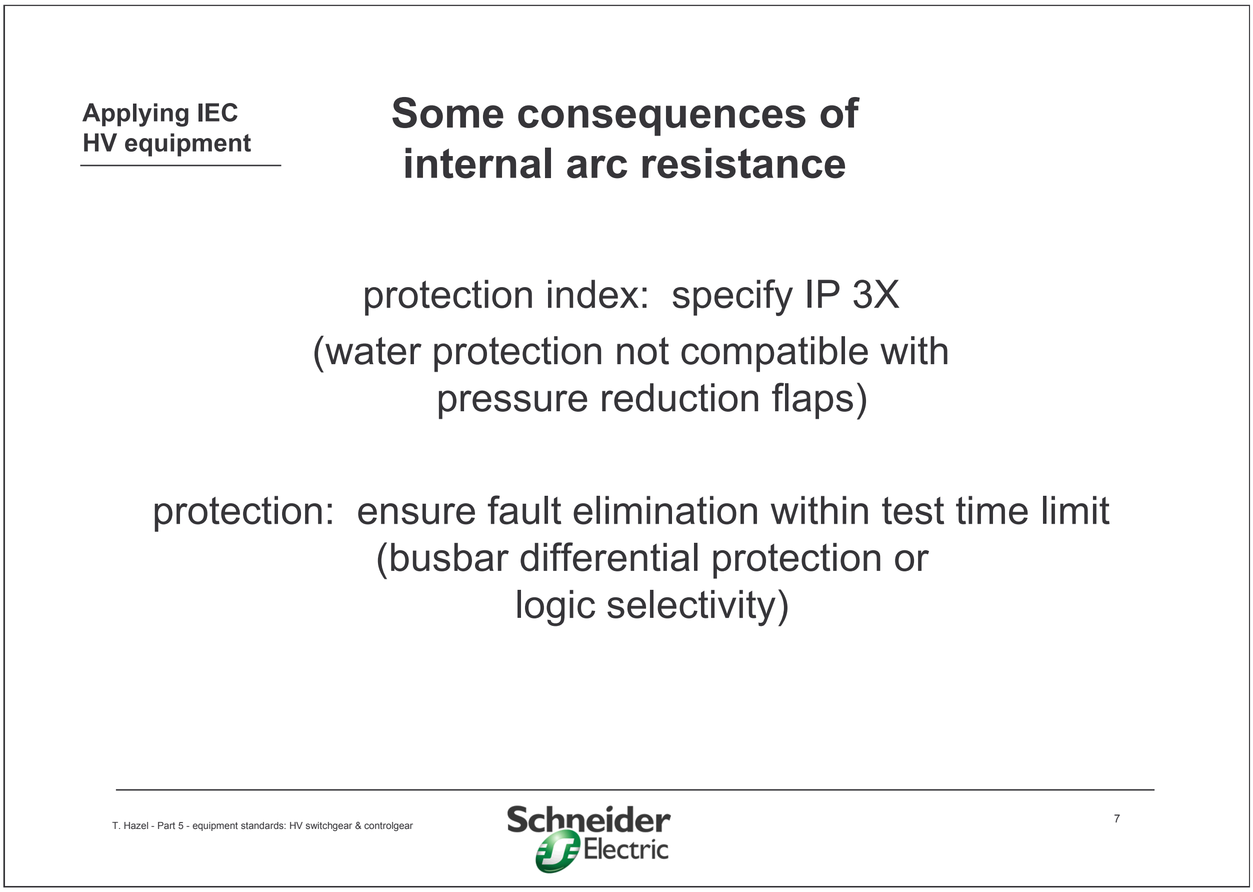
The consequences of internal faults are largely determined by the design of the switchgear and will have an influence in the choice of the duration of the short-circuit current and other parameters of the test setup. IEC62271-200 has redefined the internal arc withstand tests as type tests. In the previous standard IEC60298 they were defined as special tests subject to the agreement between purchaser and seller.

The test current used can have an effect on the choice of protection gear required for the application. For example busbar differential protection or an equivalent high-speed protection may be required to limit the duration of the short-circuit current to a value compatible with that used for the testing.



Some consequences of internal arc resistance

protection index: specify IP 3X
(water protection not compatible with
pressure reduction flaps)

protection: ensure fault elimination within test time limit
(busbar differential protection or
logic selectivity)

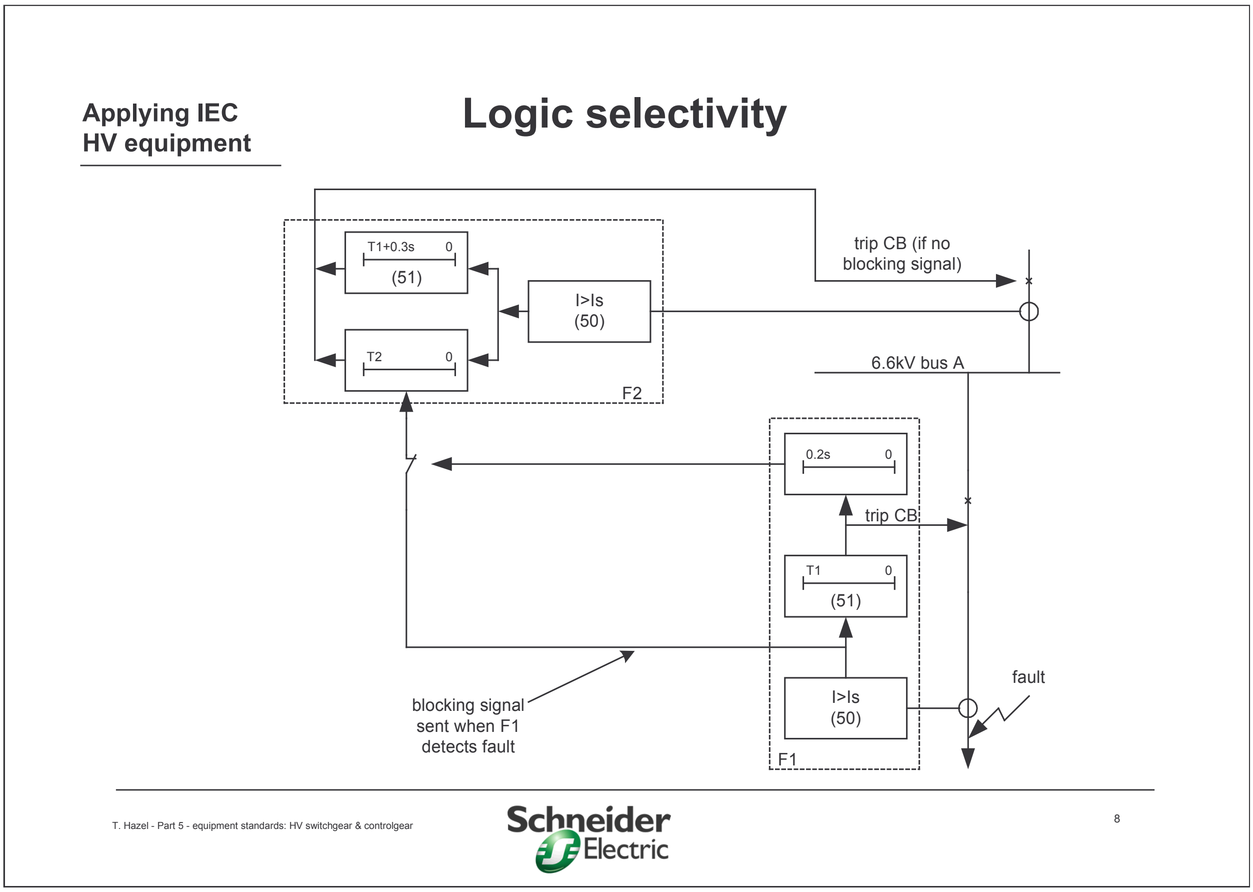
protection index

Since hot gasses must be able to escape freely towards the top of the switchboard, it is strongly recommended to specify IP3X or IP4X. This allows manufacturers to design pressure relief flaps without considering water ingress. IPX1 or more will require some sort of extra compartment on top of the switchboard to allow hot gasses to escape but prevent water from entering the cubicles.

protection

In order to ensure safety of operating personnel, the fault in the switchboard must be eliminated within the time period corresponding to the thermal effects (holes in envelope etc.). Time graded protection alone may not be quick enough.

Busbar protection can be used but this is normally provided only for main switchboards. Logic selectivity is a standard feature of multifunction protection relays and can provide quick fault elimination.



Applying IEC HV equipment

Logic selectivity

T1+0.3s
0
(51)
T2
0
I>Is
(50)
F2
trip CB (if no blocking signal)
6.6kV bus A
0.2s
0
trip CB
T1
0
(51)
I>Is
(50)
F1
fault
blocking signal sent when F1 detects fault

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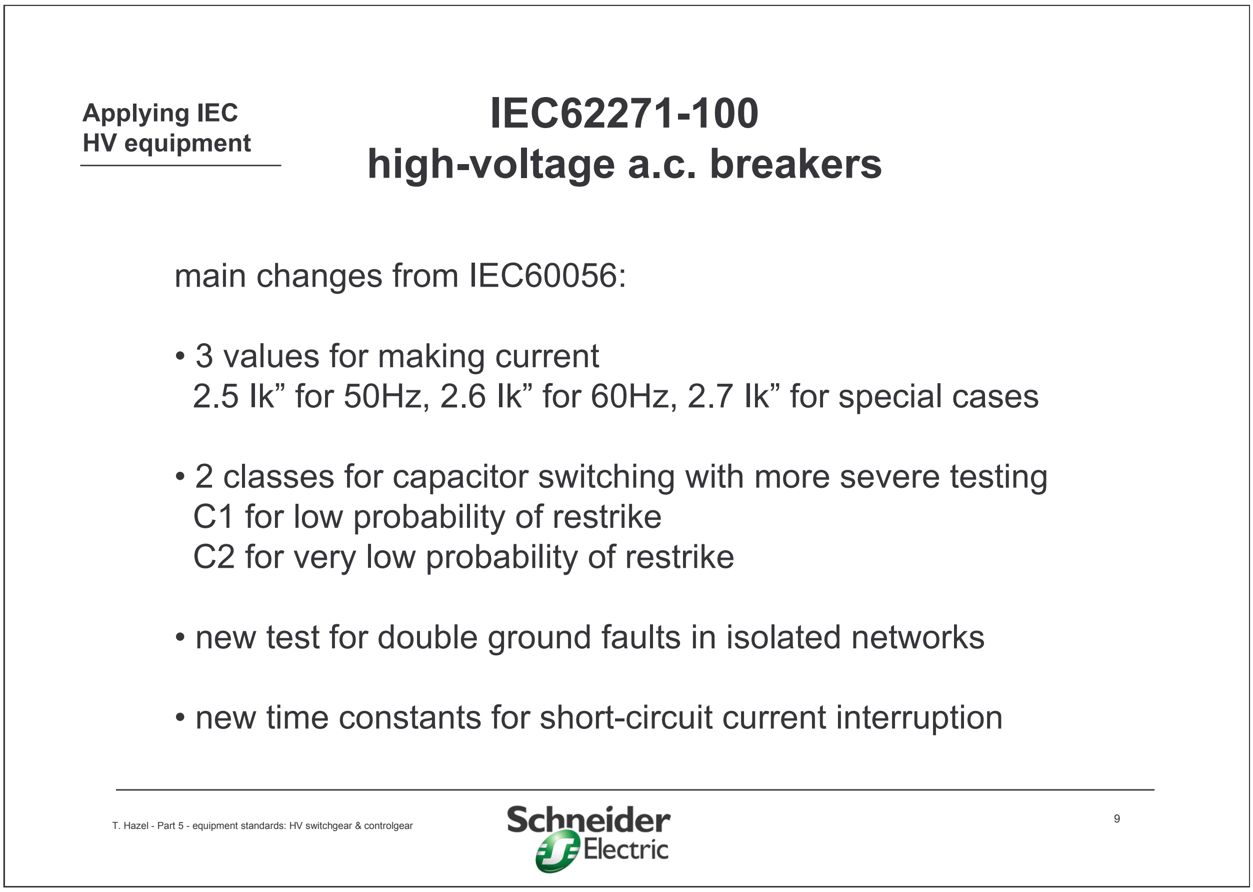
logic selectivity

When a downstream relay (F1) detects fault current, it sends a blocking signal to the upstream relay (F2). This relay also sees the fault current but does not trip its associated circuit-breaker due to the blocking signal. Under normal circumstances F1 will clear the fault. Should the fault be upstream of F1 (busbar fault for example), F1 will not send a blocking signal to F2. F2 will send a trip signal to its associated circuit-breaker without delay causing deenergization of the switchboard. The time required by F2 is similar to that achieved when busbar protection is used.

If F1 is faulty no blocking signal will be sent an F2 will trip the incoming circuit-breaker. This corresponds to standard back-up protection.



IEC62271-100
high-voltage a.c. breakers

main changes from IEC60056:

- 3 values for making current
  2.5 Ik” for 50Hz, 2.6 Ik” for 60Hz, 2.7 Ik” for special cases

- 2 classes for capacitor switching with more severe testing
  C1 for low probability of restrike
  C2 for very low probability of restrike

- new test for double ground faults in isolated networks

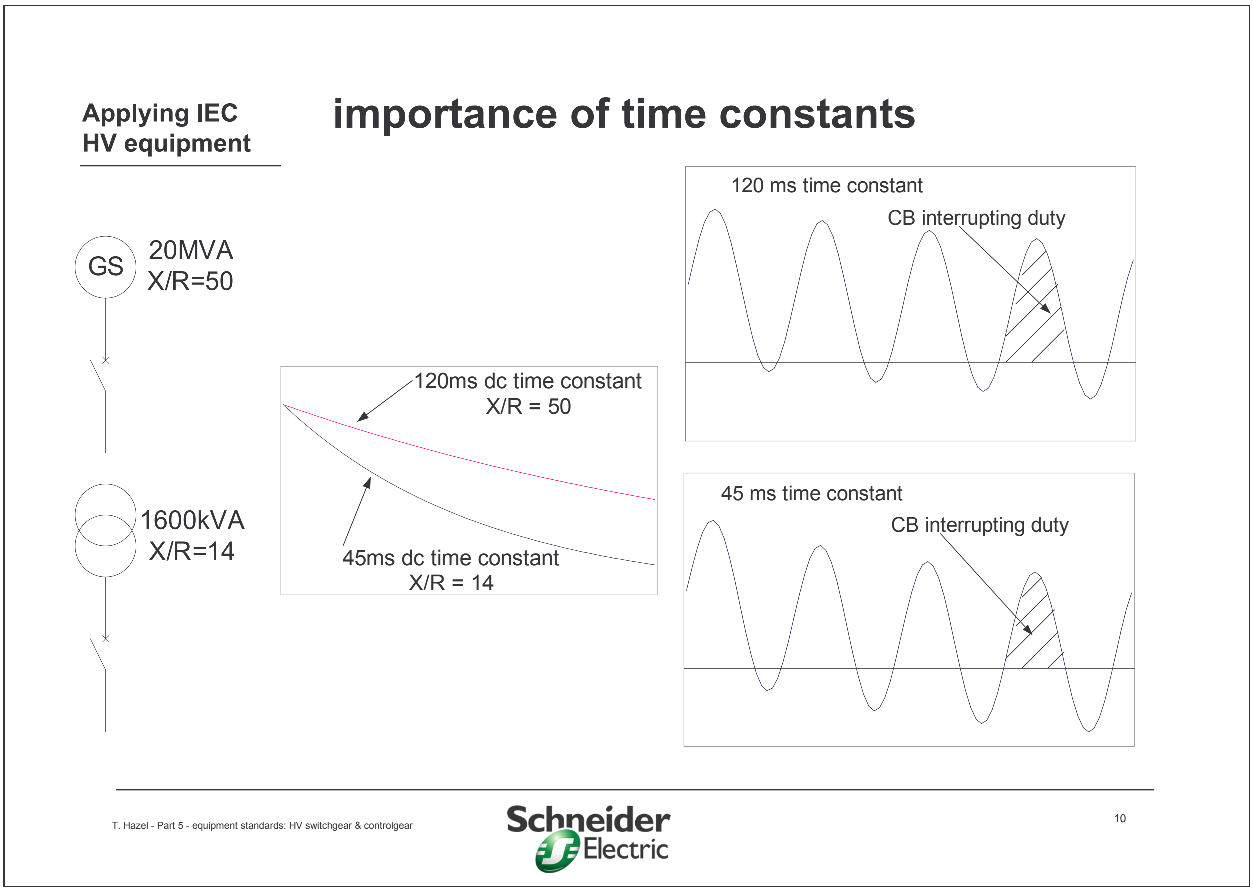
- new time constants for short-circuit current interruption

new standard

IEC60056 has been reissued as IEC62271-100. The new standard contains many important revisions and new clauses. The standard has 285 pages in English (a total of 575 pages) which shows the importance of such equipment.

The new time constants applicable for the short-circuit interrupting rating of circuit-breakers will be addressed. For a more detailed description of the subject please refer to the document “IEC Medium-Voltage Circuit-Breaker Interrupting Ratings - Unstated Short-Circuit Considerations” in the annex.

Note: ANSI C37.06 -1997 was modified in order to have the same preferred rating for peak current (closing and latching current). The values listed in ANSI C37.06 are now based on a multiplier of 2.6 instead of the previous value of 2.7 in order to be harmonized with the new IEC standard.



importance of time constants

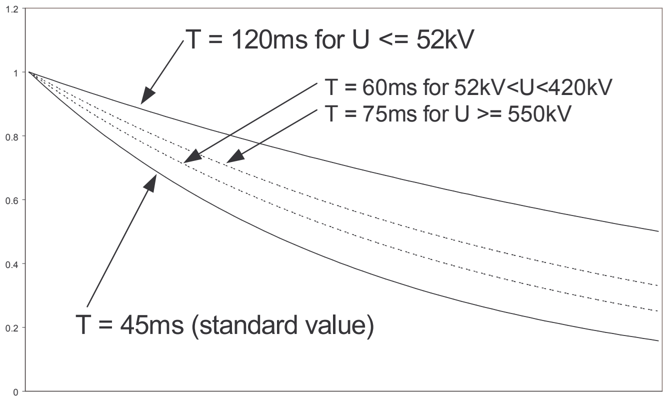
GS
20MVA
X/R=50
1600kVA
X/R=14
120ms dc time constant
X/R = 50
45ms dc time constant
X/R = 14
120 ms time constant
CB interrupting duty
45 ms time constant
CB interrupting duty

dc component

A 3-phase short-circuit will result in a dc component in the current in at least 2 phases. The dc component increases the total amount of current to be interrupted during the half cycle after the circuit-breaker poles have separated. This results in increased heat dissipation in the circuit-breaker. This can be seen by comparing the 2 waveforms shown above, one having a time constant of 120ms, the other a time constant of 45ms. The time-current integral is much larger for the current having a higher dc component. Since the arc voltage can be considered to be roughly constant prior to fault clearance, the heat dissipated is proportional to this area.

From this it is evident that the dc component in the short-circuit current will have an impact on the short-circuit current interrupting capability of a circuit-breaker.

new IEC60056 time constants



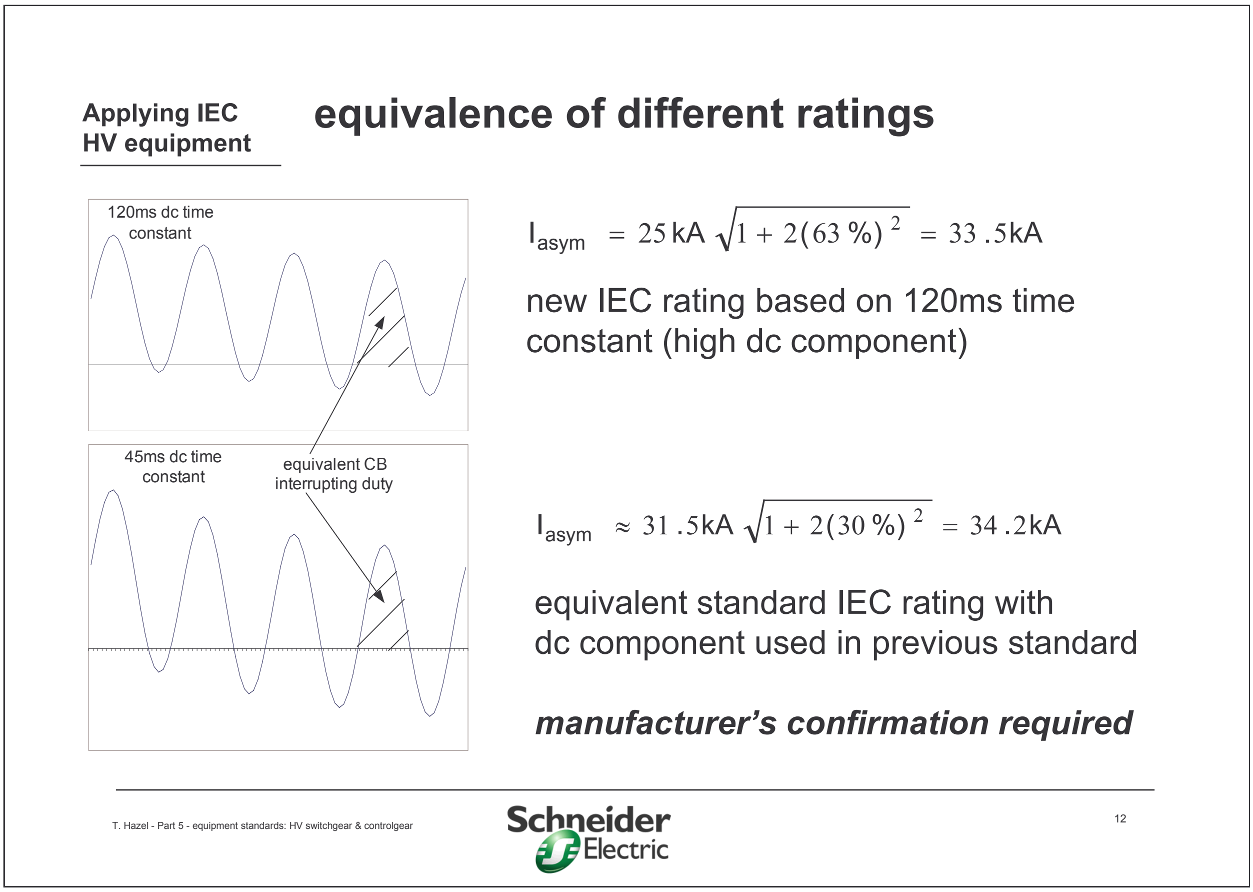
- **provides standard values for severe duties**
- **may lead to dual ratings for circuit-breakers**

new time constants

The 3 new time constants are considered typical for different applications. The largest time constant applies to industrial installations due to the high X/R ratios of generators and large power transformers.

There is no obligation in the new standard to test circuit-breakers based on these new time constants. These values are however recommended for use when the interrupting capability of circuit-breakers is to be demonstrated for short-circuit currents having a dc component with a time constant > 45ms. This will lead to standardization of such values.

At the end of IEC62271-100 is a reprint of the CIGRE paper “Specified time constants for testing asymmetric current capability of switchgear”. This paper contains background information on this subject.


120ms dc time constant
45ms dc time constant
equivalent CB interrupting duty

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equivalence of different ratings

$$I_{asym} = 25\,\text{kA}\sqrt{1 + 2(63\,\%)^2} = 33.5\text{kA}$$

new IEC rating based on 120ms time constant (high dc component)

$$I_{asym} \approx 31.5\text{kA}\sqrt{1 + 2(30\,\%)^2} = 34.2\text{kA}$$

equivalent standard IEC rating with dc component used in previous standard

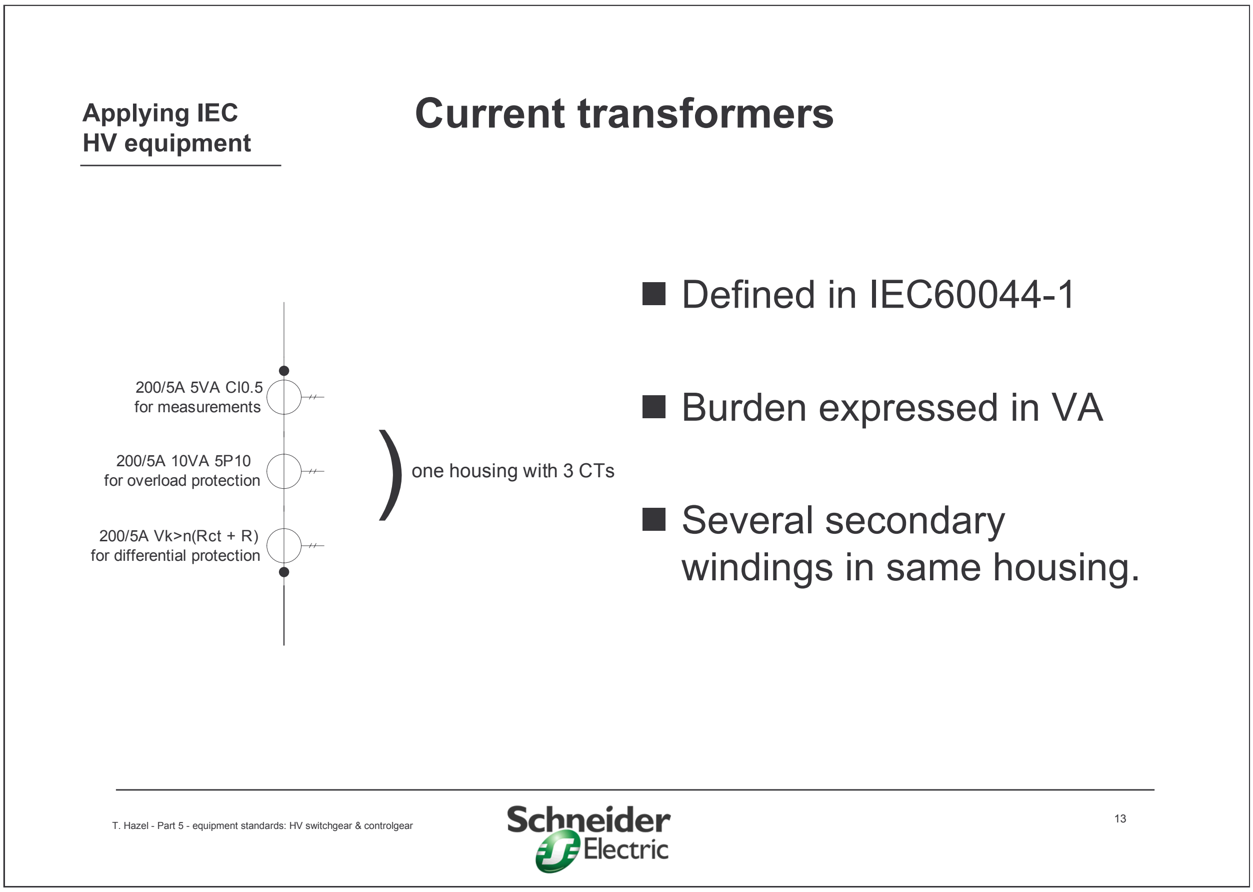
manufacturer's confirmation required

use of asymmetrical current

In the example above, a circuit-breaker rated at 31.5kA with a dc component of 30% (the IEC60056 standard 45ms time constant) has an asymmetrical interrupting rating of 34.2kA. Using the equivalence of asymmetrical currents with different dc component time constants, it can be seen that this circuit-breaker should be able to interrupt 25kA having a dc component of 63% (a time constant of 120ms).

In cases of non-standard performance, it is always necessary to obtain confirmation from the manufacturer prior to ordering equipment. The new standard will facilitate the choice of circuit-breakers since there is now a broader definition of "standard" performance concerning interrupting ratings.

Test laboratories sometimes use the equivalence described above to adjust the interrupting current by modifying the symmetrical current rather than the dc component. This is permitted by the IEC standard.



Applying IEC HV equipment

Current transformers

200/5A 5VA Cl0.5
for measurements

200/5A 10VA 5P10
for overload protection

200/5A Vk>n(Rct + R)
for differential protection

one housing with 3 CTs

- Defined in IEC60044-1
- Burden expressed in VA
- Several secondary windings in same housing.

specification of current transformers

Application of current transformers in accordance with IEC standards is often a source of confusion due to both the definition of the characteristics and how they are manufactured by IEC equipment vendors. Instrument transformers for industrial applications are covered by the IEC60044 set of standards.

IEC60044-1 current transformers covers those used in industrial applications. This standard cancels and replaces IEC185. IEC60044-6 covers specific requirements for transient performance of protective current transformers which is important for utilities but has limited use in the industrial sector.

An important addition to this set of standards is part 8. It defines the characteristics of electrical current transducers which basically are current transformers which generate low power signals. Since much equipment uses microprocessors and has a low burden, it is no longer necessary to use large magnetic core current transformers. These transducers generally have a much broader range of primary current than magnetic current transformers and therefore need not be changed should the rated current of the load change.

For the purposes of this tutorial, all references hereafter refer to IEC60044-1.

standard values for current transformers

Sub-clauses 2.2.1 and 2.3.1 define 2 types of current transformers

measuring current transformers intended to supply indicating instruments, integrating meters etc.

protective current transformers intended to supply protective relays

The burden of current transformers is expressed in VA absorbed at a specified power factor which is normally 0.8 lagging for testing purposes. Sub-clause 4.4 specifies the standard burdens which are 2.5 – 5 – 10 –15 – 30 VA.

The standard values of rated primary current are given in sub-clause 4.1.1 and are close to but not exactly the same as the R10 series. These are 10 – 12.5 – 15 – 20 – 25 – 30 – 40 – 50 – 60 –75 and their decimal multiples or fractions, the preferred values being underlined.

The standard values of rated secondary current are 1A, 2A and 5A with 5A being preferred value as per sub-clause 4.2.

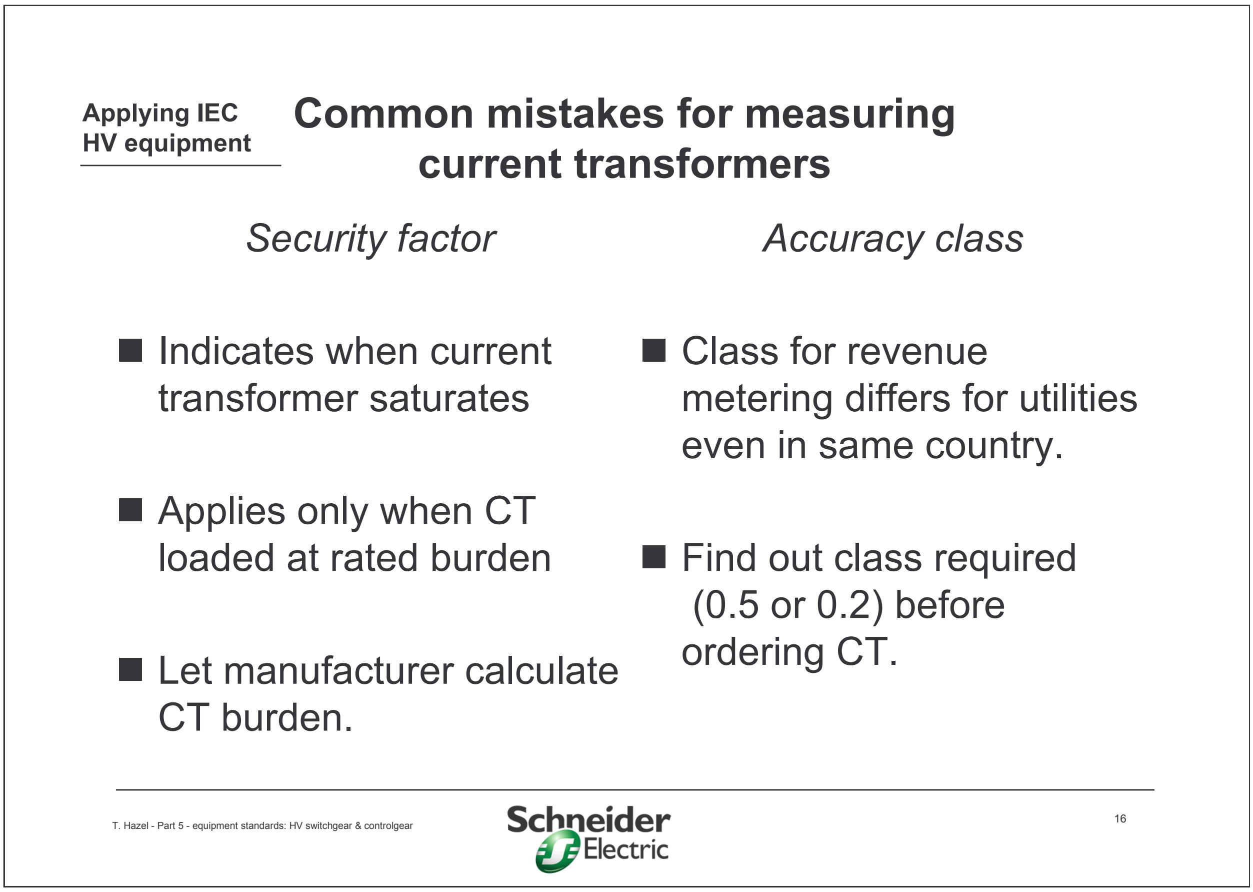
current transformers supplied by different vendors

When current transformers used for the same protection function (such as differential protection) are supplied by different vendors such as a switchgear manufacturer and a generator manufacturer, the vendor supplying the protection relay should specify the current transformer requirements. These should include the ratio, secondary limiting e.m.f., internal resistance, and limits on the magnetizing current. It is not always possible for one vendor to supply loose current transformers to be used by the other vendor since they may not fit in his equipment.

multiple current transformers

Often several current transformers are required for the same circuit. IEC equipment manufacturers often include several current transformer windings in the same housing, each current transformer having its own magnetic circuit. This is identified on drawings by using 2 dots as shown above. When separate current transformer windings are required for protection and measurement they should be specified as *separate secondary windings* and not as *separate current transformers*. Specifying separate current transformers could imply separate housings, not just separate windings.

In addition due to requirements to reduce the physical size of switchgear, manufacturers of IEC equipment often do not allow current transformers to be placed between the busbar and the circuit-breaker, nor on both sides of bus-tie circuit-breakers.



Common mistakes for measuring current transformers

Security factor

- Indicates when current transformer saturates
- Applies only when CT loaded at rated burden
- Let manufacturer calculate CT burden.

Accuracy class

- Class for revenue metering differs for utilities even in same country.
- Find out class required (0.5 or 0.2) before ordering CT.

measuring current transformers

The accuracy classes for measuring current transformers defined in sub-clause 11.1.1 are 0.1– 0.2 – 0.5 –1 – 3 – 5, each value being the percentage current error.

There are 2 problems that frequently occur in defining measuring current transformers. These are

- ☐ incorrect application of the instrument security factor FS
- ☐ incorrect definition of the accuracy class

instrument security factor

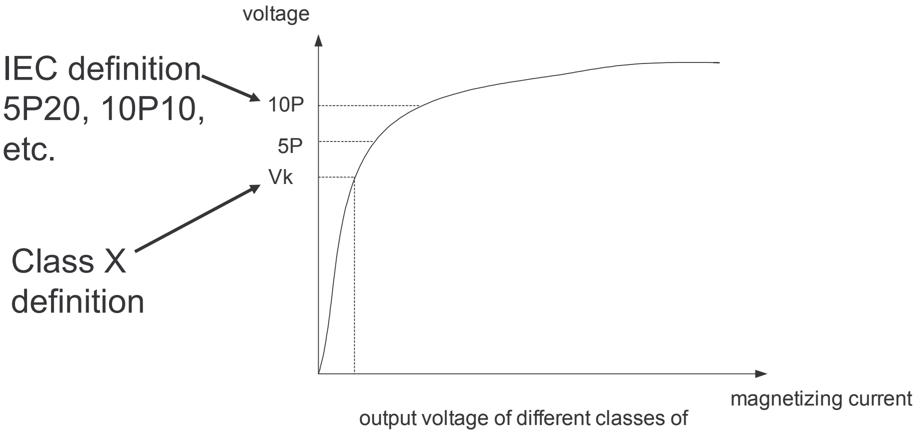
The instrument security factor is the ratio of the limit primary current to the rated primary current and thus indicates when the current transformer will saturate. Saturation protects measuring instruments from high currents which could damage them. Saturation at a value of primary current equal to *FS x rated primary current* is only true when the actual burden of the current transformer is close to its rated burden. Lightly loaded current transformers will saturate at much higher values of primary current. Specifications often require current transformers with a high rated burden but also specify a low value of FS. These are contradictory requirements. The value of FS should be specified but the rated burden determined by the manufacturer during the project execution based on the real load connected to the current transformer.

accuracy class

The accuracy class of the current transformer used for revenue metering is determined by the utility which supplies the site with power. This will vary from one utility to another even in the same country and must be confirmed prior to manufacturing. If the accuracy class is insufficient, either the utility will refuse to supply power, or it will add a penalty equal to the consumed energy times the difference in accuracy class of the current transformer and the accuracy class the utility requires. Accuracy classes of 0.5 and 0.2 are typical for revenue metering.

Class 1 is normally adequate for all other measurement current transformers.

Protective current transformers



IEC definition 5P20, 10P10, etc.

Class X definition

output voltage of different classes of current transformers

protective current transformers

Most confusion occurs with protective current transformers. This is due to the IEC definition being based on the output current rather than the output voltage. The definition based on the output voltage has been included in the new edition of IEC60044-1 and is called class PX.

Definition of protective current transformers

5P20 etc.

- Normally used for overload, over-current protection.
- Internal resistance not specified in this definition. Sometimes difficult to apply.

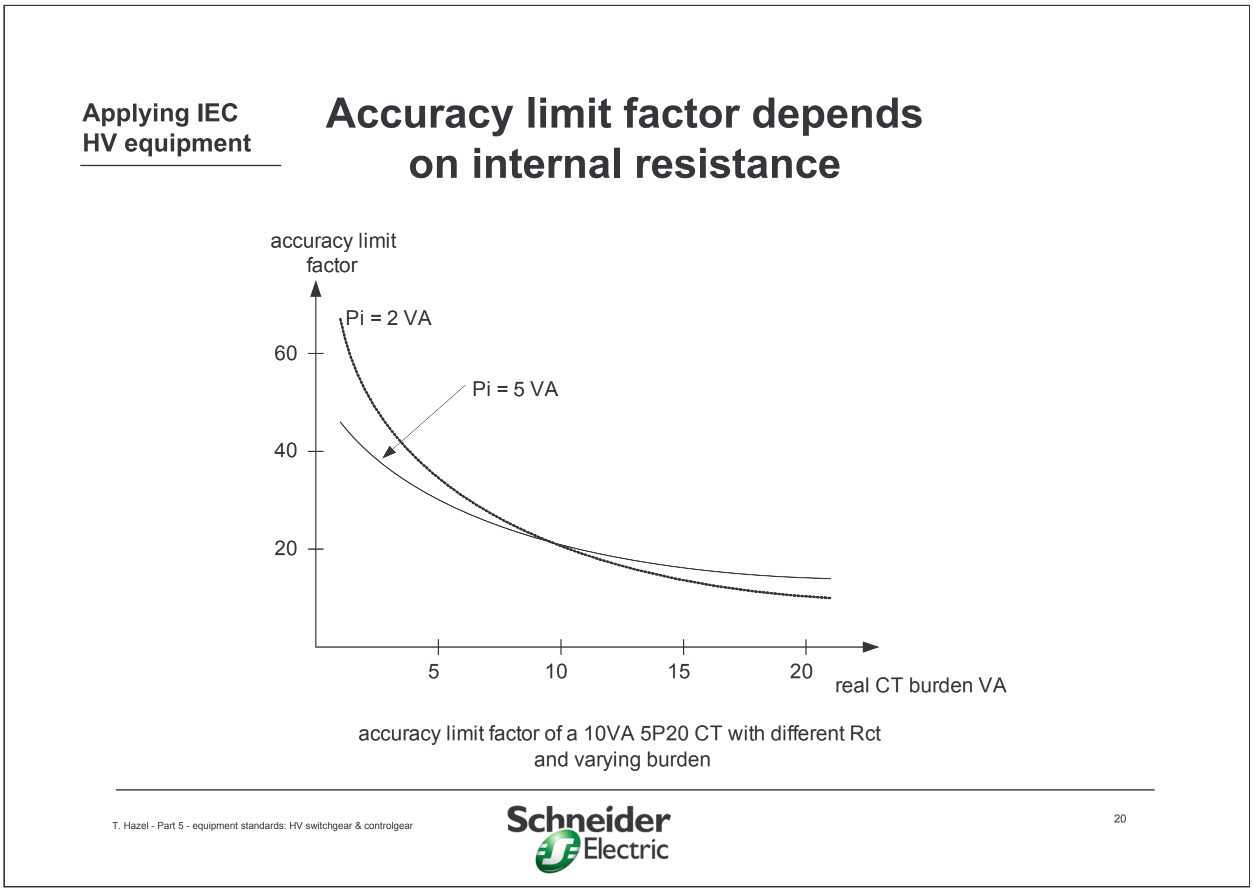
Class X

- Used for differential and line protection.
- Specifies internal resistance Vk ≥ n(Rct + r)

In a typical definition *100/5A 10VA 5P10* based on the IEC definition, *10VA* is the rated burden, *5P* is the accuracy class, and *10* is the accuracy limit factor which is a multiplier of the rated primary current.

The standard accuracy classes for protective current transformers are 5P and 10P as defined in sub-clause 12.2.2. The number 5 or 10 is equal to the percentage current error at the primary limit current which in the example above is 10 x 100A = 1000A. The error at 1000A is maximum 5%. The standard accuracy limit factors 5 – 10 – 15 – 20 – 30 are given in sub-clause 12.1. In addition at rated current the percentage current error is ±1% for 5P and ±3% for 10P current transformers.

The class X (PX) definition specifies a value of knee-point voltage and includes the internal resistance of the current transformer. The knee-point voltage Vk is the point on the voltage/excitation current curve where an increase in voltage of 10% requires an increase in magnetizing current of 50%. It is more precise than the 5P and 10P IEC definitions as can be seen from the voltage versus magnetizing current graph above.



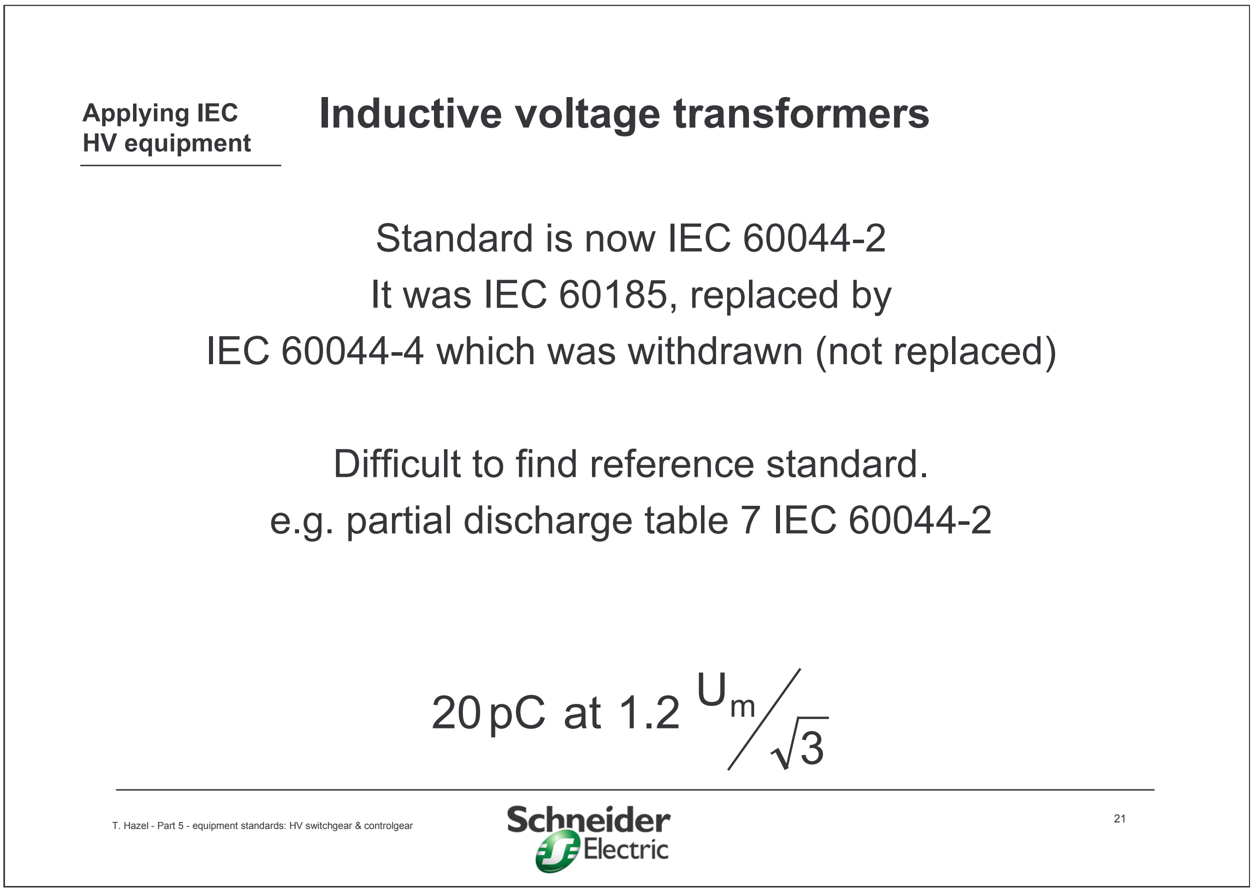
Applying IEC HV equipment

Accuracy limit factor depends on internal resistance

accuracy limit factor of a 10VA 5P20 CT with different Rct and varying burden

example application

In some cases it is not evident if the current transformer proposed by a manufacturer meets the requirements of the application. Please refer to the attached *cahiers techniques* for some examples.



Applying IEC
HV equipment

Inductive voltage transformers

Standard is now IEC 60044-2
It was IEC 60185, replaced by
IEC 60044-4 which was withdrawn (not replaced)

Difficult to find reference standard.
e.g. partial discharge table 7 IEC 60044-2

$$20\,\text{pC at } 1.2\, {}^{U_m}\!/_{\sqrt{3}}$$

inductive voltage transformers

Finding the applicable standard is not always straight forward, for example finding the acceptable levels of partial discharge for voltage transformers. IEC60186 was replaced by IEC60044-4 which was simply withdrawn (not replaced by another standard). To find IEC60044-2 it was necessary to do a key-word search on the IEC website.

standard values for voltage transformers

Sub-clauses 2.1.31 and 2.2.1 define 2 types of voltage transformers.

measuring voltage transformer intended to supply indicating instruments, integrating meters etc.

protective voltage transformers intended to supply protective relays

The rated primary voltage defined in sub-clause 5.1.1 corresponds to a nominal system voltage defined in IEC60038 such as 6.6kV or 69kV.

Voltage transformers

Specify rated voltage factor based on neutral earthing.

Total rating of multiple winding voltage transformers

$$\leq$$

$$\sum$$ (rating of each winding).

A rated voltage factor as defined in sub-clause 5.3 should always be given for voltage transformers. This factor indicates the upper limit of voltage which can be applied to the transformer and for how long. The factor varies from a lowest value of 1.2 for continuous operation to 1.9 for 8 hour operation.

The choice of the appropriate factor depends on how the voltage transformer is connected and how the neutral point of the system is earthed. For example when an isolated neutral system is used and there is no immediate tripping when an earth fault occurs, voltage transformers connected phase to earth should be specified with a rated voltage factor of 1.9 for 8 hours.

Also, as per §5.2, “The rated output of a three-phase transformer shall be the rated output per phase.” This is due to the necessity of linking a rated output with a standard accuracy class for testing purposes.

Rated secondary line-to-line voltages are defined in sub-clause 5.1.2 and are

☐ 100V and 110V for European countries
☐ 120V and 115V in USA and Canada

The standard values of rated output defined in sub-clause 5.2 are 10, 15, 25, 30, 50, 75, 100, 150, 200, 300, 400, 500 VA, the underlined values being preferred. For cases where a 3-phase voltage transformer is used, the rating is of one phase. This is not common in industrial applications however.

total rating of multiple winding voltage transformers

Each winding has rated output in VA but the total rating of the voltage transformer is not necessarily the sum of the VA of each winding. This is normally not very important since voltage transformers are rarely heavily loaded. Again, the best method of ensuring correct definition of the voltage transformer is for the manufacturer to make a calculation note based on the metering and protection requirements and for you to review it.

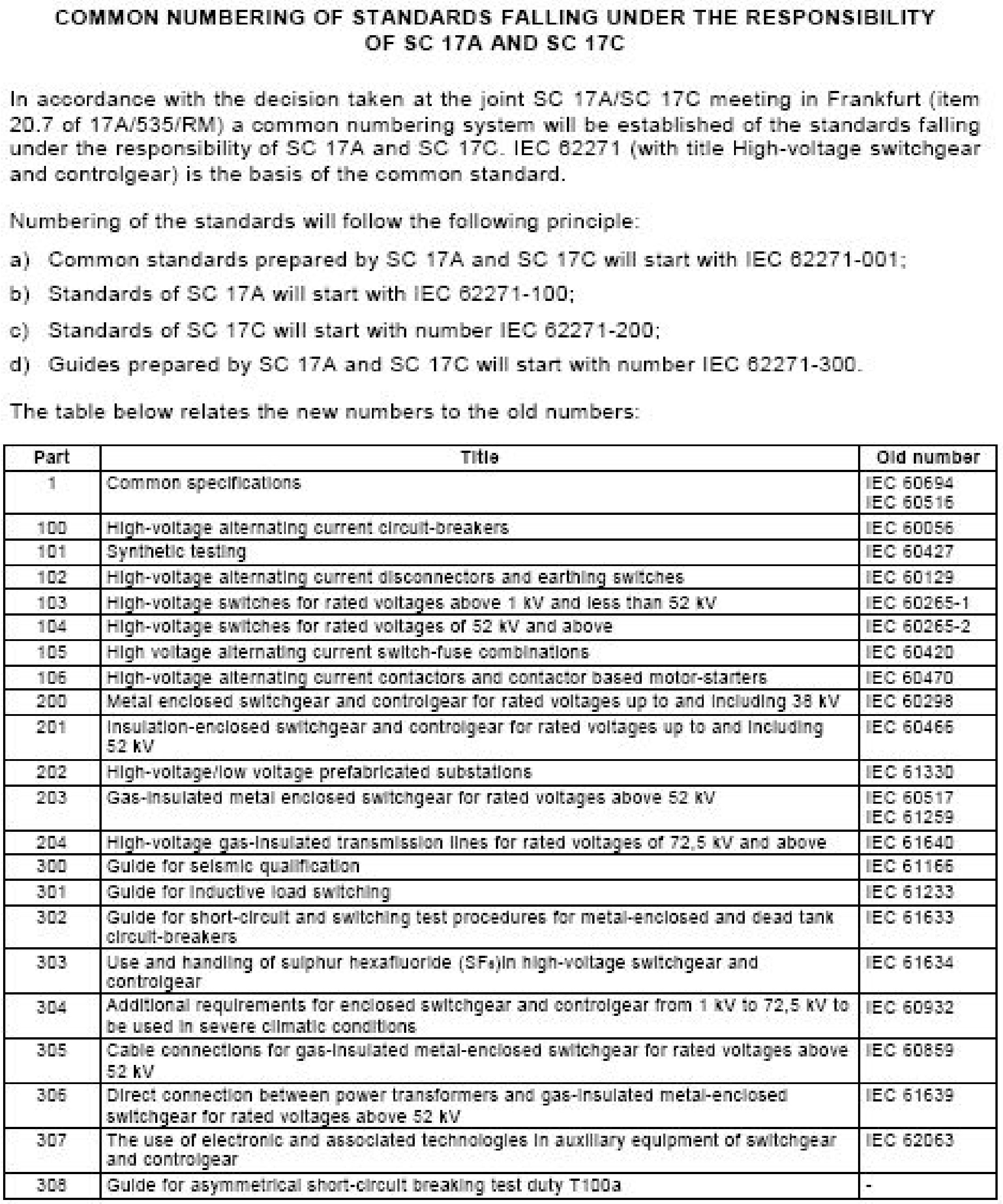
measuring voltage transformers

The standard accuracy classes for measuring voltage transformers are the same as those for current transformers and are 0.1 – 0.2 – 0.5 – 1.0 – 3.0. These are given in sub-clause 12.1.1 The same care should be taken in choosing the accuracy class for revenue metering as described in section for current transformers.

protective voltage transformers

For protection voltage transformers the accuracy classes are 3P and 6P meaning the percentage voltage error from 5% voltage to the rated voltage factor is 3% respectively 6%. 3P is normally used for all protection applications.

New numbering of high-voltage equipment standards



COMMON NUMBERING OF STANDARDS FALLING UNDER THE RESPONSIBILITY OF SC 17A AND SC 17C

In accordance with the decision taken at the joint SC 17A/SC 17C meeting in Frankfurt (item 20.7 of 17A/535/RM) a common numbering system will be established of the standards falling under the responsibility of SC 17A and SC 17C. IEC 62271 (with title High-voltage switchgear and controlgear) is the basis of the common standard.

Numbering of the standards will follow the following principle:

a) Common standards prepared by SC 17A and SC 17C will start with IEC 62271-001;

b) Standards of SC 17A will start with IEC 62271-100;

c) Standards of SC 17C will start with number IEC 62271-200;

d) Guides prepared by SC 17A and SC 17C will start with number IEC 62271-300.

The table below relates the new numbers to the old numbers:

Part	Title	Old number
1	Common specifications	IEC 60694 IEC 60516
100	High-voltage alternating current circuit-breakers	IEC 60056
101	Synthetic testing	IEC 60427
102	High-voltage alternating current disconnectors and earthing switches	IEC 60129
103	High-voltage switches for rated voltages above 1 kV and less than 52 kV	IEC 60265-1
104	High-voltage switches for rated voltages of 52 kV and above	IEC 60265-2
105	High voltage alternating current switch-fuse combinations	IEC 60420
106	High-voltage alternating current contactors and contactor based motor-starters	IEC 60470
200	Metal enclosed switchgear and controlgear for rated voltages up to and including 38 kV	IEC 60298
201	Insulation-enclosed switchgear and controlgear for rated voltages up to and including 52 kV	IEC 60466
202	High-voltage/low voltage prefabricated substations	IEC 61330
203	Gas-insulated metal enclosed switchgear for rated voltages above 52 kV	IEC 60517 IEC 61259
204	High-voltage gas-insulated transmission lines for rated voltages of 72,5 kV and above	IEC 61640
300	Guide for seismic qualification	IEC 61166
301	Guide for inductive load switching	IEC 61233
302	Guide for short-circuit and switching test procedures for metal-enclosed and dead tank circuit-breakers	IEC 61633
303	Use and handling of sulphur hexafluoride (SF_6)in high-voltage switchgear and controlgear	IEC 61634
304	Additional requirements for enclosed switchgear and controlgear from 1 kV to 72,5 kV to be used in severe climatic conditions	IEC 60932
305	Cable connections for gas-insulated metal-enclosed switchgear for rated voltages above 52 kV	IEC 60859
306	Direct connection between power transformers and gas-insulated metal-enclosed switchgear for rated voltages above 52 kV	IEC 61639
307	The use of electronic and associated technologies in auxiliary equipment of switchgear and controlgear	IEC 62063
308	Guide for asymmetrical short-circuit breaking test duty T100a	-